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The internal conversion electron spectrum of $_{82}Pb^{196}$

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With 1 figure in the text

ABSTRACT

The electron spectrum of mass separated sources of Pb^{196} was studied with a momentum resolution of about 0.5 % in a double focusing β-spectrometer. The following tentative level scheme of Tl^{196} is proposed: ground state (2 −), 191.8 (0 −), 240.3 (2 −), 253.2 (1 − or 2 −), 366.6, 494 and 503 keV.

1. Introduction

The decay of Pb^{196} has previously been studied by Andersson *et al.* [1], who reported a half-life of 37 ± 3 minutes and some conversion electron lines. Later measurements, also performed at this Institute, clarified some ambiguities in the earlier work, the conversion electron data of which were now interpreted as establishing γ-transitions of the following energies and multipolarities: 191 keV (E2), 239.7 keV (M1) and 252.9 keV (M1), and also a coincidence relation between the last two transitions. The re-interpretation was privately communicated to the Nuclear Data Group [2].

The level structure of Tl^{196} is of special interest, since this nucleus is a member of one of the very few series of odd-odd nuclei, in which, at present, the systematics of levels can be studied as a function of the neutron number. Recent theoretical studies by de-Shalit and Walecka [3] of the level splitting in odd-odd nuclei due to the interaction between the odd proton and the odd neutron also give importance to the experimental study of these nuclei. A more detailed comparison of theory and experiment appears, however, to be rather difficult because of incomplete empirical information and ambiguity in the assignment of proton-neutron configurations to the levels established experimentally.

2. Experimental procedures

All sources were prepared in the mass separator [4] of this Institute, following bombardments of TlCl in the Werner synchrocyclotron with 120 MeV protons and chemical separations [5]. The conversion electron spectrum was studied in a double focusing β-spectrometer [6], adjusted to a momentum resolution of about 0.5 %. Two different techniques were applied in the measurements, the first being an automatic scanning of overlapping parts of the spectrum between 100 and 1000 keV with a registration of the counting rate by means of a rate-meter and a strip-chart recorder [6], the second a more careful measurement of individual peaks, assigned to Pb^{196}

Table 1. Internal conversion lines in the decay of Pb^{196}.

Conversion ratios within parentheses are interpolated from Rose [9] and Sliv and Band [10] for the suggested multipole order. Mean values are given where the two theoretical calculations differ.

Adopted transition energy (keV) and multipolarity	Conv. shell	Electron energy (keV)	Relative electron intensity	Conversion ratios		Relative total transition intensity
191.8 ± 0.4	K	106.3 ± 0.4	13 ± 2	$K/L = 0.8 \pm 0.2$	(0.8)	34 ± 5
$E2$	L_{II}	177.2 ± 0.9	9 ± 2	$L_{II}/L_{III} = 1.7 \pm 0.6$	(1.6)	
	L_{III}	179.5 ± 0.9	6 ± 2	$L/M = 2.1 \pm 0.8$		
	M	189.0 ± 1.0	8 ± 2	$M/N = 5 \pm 2$		
	N	191.5 ± 0.9	1.5 ± 0.7			
240.3 ± 0.4	K	154.8 ± 0.4	34 ± 4	$K/L \geqslant 2.8$	(6.1)	31 ± 4
$M1\ (+ < 20\%\ E2)$	L	225.4 ± 1.0	$\leqslant 12$	$K/L_{III} > 60$		
253.2 ± 0.4	K	167.7 ± 0.4	100	$K/L = 5.4 \pm 0.9$	(6.1)	100
$M1$	L	238.2 ± 1.3	18 ± 4	$L/M = 5 \pm 3$		
	M	249.8 ± 1.5	3.5 ± 1.0			
366.6 ± 1.0	K	281.1 ± 1.0	18 ± 6	$K/L > 5$	(6.0)	38 ± 12
$M1$						
494 ± 2	K	409 ± 2	4 ± 2			17 ± 9
$(M1)$						
503 ± 2	K	418 ± 2	21 ± 2	$K/L = 5 \pm 2$	(6.0)	90 ± 9
$(M1)$	L	488 ± 3	4 ± 2			

from the first type of measurements, with an improved automatic operation of the spectrometer [7]. The energy region between 5 and 100 keV was studied exclusively with the improved automatic operation, in which the spectrometer current is increased step-wise and the number of counts for a preset time is registered digitally. The half-lives of the lines were studied by repetitive scannings of the spectrum. The energy calibration was made from measurements on composite sources of Pb^{196} and ThB, and the relative intensities of the lines were obtained from numerical integrations of the peaks, recorded in the second type of measurements. Saxon's diagrams [8] were used to correct for the absorption in the detector window (0.05 mg/cm² VYNS in measurements below 110 keV and 0.9 mg/cm² Mylar for higher energies).

3. Results

3.1. *Conversion electron spectrum*

Conversion lines of the γ-transitions, which we confidently assign to the decay of Pb^{196}, are collected in Table 1. The multipolarities of the transitions were inferred from comparisons of the experimental conversion ratios with theoretical values, derived from the internal conversion coefficients, calculated by Rose [9] and Sliv and Band [10]. These coefficients were also used in the estimates of the relative total transition intensities (cf. Table 1), $M1$ multipolarity being assumed for the 494 and 503 keV transitions. The apparently low K/L ratio of the 240 keV transition is probably caused by a line of different origin, interfering with the L_I line. A much lower value (20 %) of possible $E2$ admixture to the transition can be calculated from the K/L_{III} ratio than is indicated by the K/L ratio. Since there is no evidence for $E2$ admixture, pure $M1$ multipolarity is assumed. The K 367 keV line was found to have

Table 2. Unassigned lines.

The transitions listed in column 4 are accommodated by the proposed level scheme.

Electron energy (keV)	Rel. electron intensity (K 253 = 100)	Possible conv. shells	Proposed assignment
19.3 ± 0.2	5 ± 2	K, L, M	
27.8 ± 0.2	10 ± 3	K, L	K 113
40.9 ± 0.3	6 ± 2	K, L	K 126
41.6 ± 0.4	6 ± 2	K, L	K 127
42.5 ± 0.4	3 ± 2	K, L	
81.2 ± 0.4	7 ± 2	K	
84.2 ± 0.7	3 ± 2	K, L	
88.3 ± 0.9	8 ± 3	K, L	K 175
101.7 ± 0.9	4 ± 3	K, L	
156.2 ± 0.9	4 ± 1	K, L	K 241
216.2 ± 1.1	1.2 ± 0.5	K, L, M	K 302

a long-lived admixture, which explains why rather wide intensity limits were attributed to this line.

In Table 2 we have listed the conversion lines, for which the conversion-shell assignment or the conversion element, or both, are uncertain, Pb^{195} and Pb^{197} being the alternatives to Pb^{196}. As indicated in the table, some of the lines can be interpreted as K conversion lines of transitions in the proposed level scheme of Tl^{196} (cf. Fig. 1). The good agreement between the transition energies, calculated from the level scheme and from the conversion lines of Table 2, gives in some cases rather strong support to the interpretation of these lines as emitted in the decay of Pb^{196}.

By following the decay of the K 253 keV conversion line in the spectrometer the half-life of Pb^{196} was measured to be 37 ± 3 minutes, in good agreement with the earlier value [1].

3.2. *Level scheme of* Tl^{196}

The spin-parity of Pb^{196}, an even-even nucleus, is certainly $0+$. The ground-state spin of Tl^{196} has not yet been measured, the most probable value being 2[a] in analogy with the measured spins of Tl^{198}, Tl^{200} and Tl^{202} [11]. Negative parity follows from the nuclear shell model.

The construction of a level scheme of Tl^{196} should be based on the six strong and well-established transitions listed in Table 1. Since the spin difference between the ground states of Pb^{196} and Tl^{196} is probably only 2 units, and there are, with one exception which will be discussed later on, no energy sum-relations between the transitions, one concludes from the intensities of the transitions that they possibly all go to the ground state. With this assumption, several of the unassigned lines in Table 2 can be interpreted as K conversion lines of transitions between the excited levels, as seen from Fig. 1. Although the evidence from each such transition is rather weak, the number of such transitions certainly give support to the proposed level scheme.

[a] *Note added in proof:* Indications of this spin value were recently found by Olsmats and Axensten, University of Uppsala, using atomic beam resonance techniques (private communication).

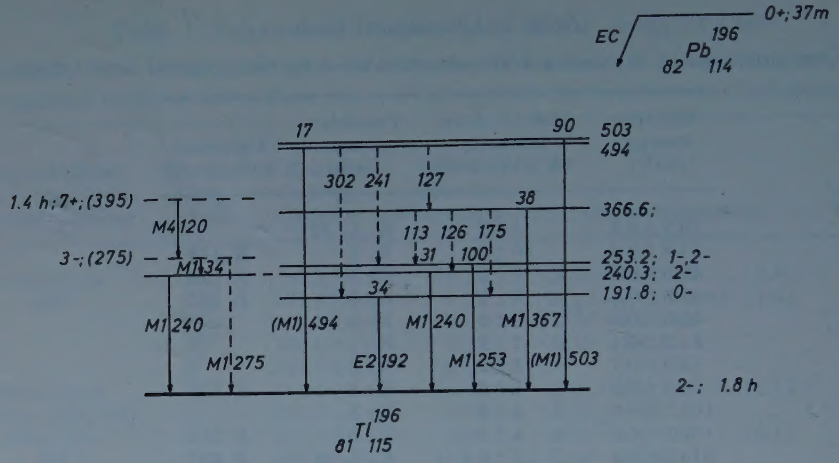

Fig. 1. Tentative level scheme of Tl^{196}. All energies are in keV and the figures at the tails of the transition arrows indicate the relative total transition intensities. The level scheme involved in the internal branch of the decay of Tl^{196m} is taken from ref. [12].

There may be some doubts, however, as to the position of the 240 keV transition in the level scheme, and consequently as to the existence of the 240 keV level. A positive coincidence effect has been found [2] between the *K* conversion lines of this and the 253 keV transitions, which is not in accordance with the proposed level scheme. A cascade relationship between the 240 and 253 keV transitions is also indicated by the 494 keV transition (cf. Table 1), which might be the cross-over transition to a 240–253 keV cascade. The reasons why the coincidence information and the energy-sum indication were not taken into account in the construction of the level scheme are as follows: (a) if the coincidence relation were true, the only position of the 240 keV transition would be on top of the 253 keV transition and from the intensities of the two transitions one then calculates (from the original data) an expected coincidence counting rate about ten times higher than was found, (*b*) there are indications of a conversion line (156.2 keV, cf. Table 2), almost coinciding in energy with the *K* 240 keV line, which might explain both the coincidence effect and the energy-sum relation and (c) a transition, probably converting in thallium, was found in the decay of Tl^{196m} [12], the energy of which coincides with the 240 keV transition within the limits of error, and which cannot precede the 253 keV transition.

Assuming the ground-state spin of Tl^{196} to be 2, the 192 keV level probably is 0 −, since otherwise the pure *E*2 character and the intensity of the 192 keV transition are difficult to account for. From information obtained in the decay of Tl^{196m} [12] the 240 keV level is concluded to be 2 −. The possible spin values of the level at 253 keV are 1 and 2, of which 1 may be suggested by the fact that the 253 keV transition was not found in the decay of Tl^{196m} [12] (the upper limit of *K* 253/*K* 240 in this decay can be calculated to be 0.25 from the original spectrum). On the other hand, a spin of 2 may be suggested by the fact that no transition from the 253 keV to the 192 keV level was found in the decay of Pb^{196} (the upper limit of the intensity of the L conversion line of this transition being 1.8 % of the *K* 253 keV line). The spin-parity of the 367 keV level might be 1 −, since indications were found of the *K* line of the transition to the 192 keV level. For similar reasons the 494 keV level may be expected to be 1 −. Since no transitions to the lower excited levels were found from the 503 keV level, even the existence of this level is uncertain. However, the K line of the conceivable transition to the 192 keV level may be responsible for the composite nature of the L 240 keV line (cf. sub-section 3.2). The 503 keV level might then be supposed to be 1 −.

4. Discussion

The systematics of the 2 − ground states and the low-lying 0 −, 2 −, 3 − and 7 + levels in even mass thallium isotopes has already been studied [12]. Since the present work does not alter the earlier adopted 2 −, 0 −, 2 −, 3 − and 7 + sequence in Tl^{196} and the information on the other levels in the nucleus is still rather scanty, it appears to be of little value to repeat the systematic treatment, especially as the association of higher low-spin states in the different nuclei is rather ambiguous.

According to the model used by de-Shalit and Walecka [3], the low-lying levels in odd-odd thallium isotopes with mass number less than 208 probably involve an $s_{1/2}$ proton coupled to a $p_{1/2}$, $p_{3/2}$, $d_{5/2}$ or $i_{13/2}$ neutron. The proton state is inferred from the odd mass thallium isotopes Tl^{195} to Tl^{207}, which all have a 1/2 + ground state, the first excited level (3/2 +) having an energy of about 380 keV (Tl^{195}, Tl^{197} and Tl^{199}). The neutron states are closer in energy, the level sequence of Hg^{195} being: ground state (1/2 −), 37 keV (3/2 −), 53 keV (5/2 −) and 176 keV (13/2 +) [13].

The low-lying 0 − level in the even mass thallium nuclei should in this model have the configuration $(s_{1/2}, p_{1/2})$ and the 3 − and 7 + levels the configurations $(s_{1/2}, f_{5/2})$ and $(s_{1/2}, i_{13/2})$, respectively. The assignment of configurations to the other levels is more uncertain, since 1 − levels can have the configurations $(s_{1/2}, p_{1/2})$ or $(s_{1/2}, p_{3/2})$ and 2 − states the configurations $(s_{1/2}, p_{3/2})$ or $(s_{1/2}, f_{5/2})$. The ambiguity is not removed by the rule for the ground-state spin, formulated by de-Shalit and Walecka [3]. This rule implies that of the pairs of states with configurations $(s_{1/2}, p_{1/2})$, $(s_{1/2}, p_{3/2})$ and $(s_{1/2}, f_{5/2})$ the state with even J should be the lower.

de-Shalit and Walecka [3] propose the configuration $(s_{1/2}, f_{5/2})$ for the second excited (2 −) levels in Tl^{198} and Tl^{196}. The ground-state configuration is then $(s_{1/2}, p_{3/2})$ and the high intensity of the low-energetic transitions between the $(s_{1/2}, f_{5/2})_{J=3}$ and the $(s_{1/2}, f_{5/2})_{J=2}$ states in these nuclei as compared to the ground-state transitions $(s_{1/2}, f_{5/2})_{J=3} \rightarrow (s_{1/2}, p_{3/2})_{J=2}$ is explained by l-forbiddeness of the latter transitions.

Of the low-spin states involving an $s_{1/2}$ proton it now remains $(s_{1/2}, p_{1/2})_{J=1}$ and $(s_{1/2}, p_{3/2})_{J=1}$. Two rather low-lying 1 − levels are found in Tl^{200} (257 and 290 keV [14]), and in Tl^{198} the level at 290 keV [5] can be due to one of the configurations, as can also the 253 keV level in Tl^{196} (assuming this level to be 1 −).

If the assignment of configurations, made in the foregoing paragraphs, is correct, the model predicts the transitions from the second excited (2 −) levels to the ground states in Tl^{198} and Tl^{196} to be l-forbidden. No evidence was found of an $E2$ admixture to the transition in Tl^{196}, but an $E2$ admixture of up to 20 % is not excluded. The K/L ratio of the corresponding transition in Tl^{198} [5] is somewhat, although not significantly, lower than the value predicted by theory [9, 10] for pure $M1$ multipolarity. The L_{I+II}/L_{III} ratio of this transition limits the possible $E2$ admixture to 25 %. Also the transitions from the 290 keV (1 −) and 253 keV (1 − ?) levels in Tl^{198} and Tl^{196}, respectively, to the second excited (2 −) levels should in this model be l-forbidden. In Tl^{198} [5] this transition competes favourably with the ground-state transition, which should not be l-forbidden. The corresponding transition in Tl^{196} was not detected, but it has a very low energy (13 keV).

We conclude that no strong arguments for or against the proposed assignment of configurations are revealed by the comparison of theory and experiments. Obviously the energy splitting within the configurations is of the same magnitude as the splitting between the different configurations, which may at least partially explain the difficulties in the assignment of configurations to the levels.

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